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COBRA 2010

The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors

Held at Dauphine Université, Paris, 2-3 September 2010

ISBN 978-1-84219-619-9

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12 Great George Street
London SW1P 3AD
United Kingdom

www.rics.org/cobra

September 2010

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All papers submitted to COBRA were subjected to a double-blind (peer review) refereeing process. Referees were drawn from an expert panel, representing respected academics from the construction and building research community. The conference organisers wish to extend their appreciation to the following members of the panel for their work, which is invaluable to the success of COBRA.

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Vulnerability reduction of infrastructure reconstruction projects

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Abstract:

Various infrastructure segments of numerous countries have been repeatedly subjected to natural and man-made disasters. The potential reason of damaging infrastructure facilities and their services is resultant disaster risks due to natural or man-made hazards connect with vulnerable infrastructure facilities and vulnerable communities. The simplest way to prevent or mitigate disaster losses is addressing vulnerabilities. The main study based on which this paper was compiled aimed at exploring and investigating the vulnerabilities of infrastructures and communities benefited from infrastructures and possible solutions to overcome them. This paper presents the literature review conducted on vulnerabilities of infrastructures and empirical evidence collated on best possible DRR strategies to overcome such vulnerabilities of infrastructures. The main study was conducted using case study strategy and the expert interviews. This paper is entirely based on the data collated from the expert interviews conducted in Sri Lanka and United Kingdom. The expert interviews discovered various DRR strategies to overcome the vulnerabilities of the infrastructure projects.

Keywords:

Disaster risk reduction, Socio-economic development, Vulnerability reduction

1 Introduction

Various infrastructure segments of numerous countries have been repeatedly subjected to natural and man-made disasters (Nigim *et al.*, 2005). When events such as natural disasters destroy infrastructures, their opportunity cost becomes painfully evident (GOI, 2002). All crucial benefits of infrastructure facilities tend to temporarily or permanently cease due to disaster risks. For instance, Freeman and Warner (2001) state that small

change in climate change result in large increases in infrastructure damage. A sudden disruption of infrastructure affects the entire humanity. Creation of significant negative consequences to infrastructure would lead to socio-economic consequences and depauperated quality of life often for long periods of time (GOI, 2002). As emphasised by authors such as Oh *et al.* (2010), major impacts on infrastructure facilities due to natural and man-made hazards could result in secondary and further a doubled up impact on the communities those who may have been already affected by the hazard in concern due to the fact that the impact on infrastructure creates a vicious cycle, amplifying the impact of the disaster to the affected community. It is a kind of a transfer of impact on the infrastructure to the community. The potential reason of damaging infrastructure facilities and their services is resultant disaster risks due to natural or man-made hazards connect with vulnerable infrastructure facilities and vulnerable communities. Prevention or mitigation of disaster risk can be achieved by prevention or mitigation of hazard and/or prevention or mitigation of vulnerabilities. But the simplest way to prevent or mitigate disasters is by addressing vulnerabilities. In order to either overcome or limit these infrastructure losses, first of all it is important to identify patterns and ways in which infrastructure facilities have so far been lost, damaged and affected due to disasters. Therefore, the main research based on which this paper was compiled aimed at exploring and investigating the existing vulnerabilities of infrastructures and possible solutions to overcome them. This paper presents the literature review conducted on vulnerabilities of infrastructures and empirical evidence collated on best possible DRR strategies to overcome such vulnerabilities of infrastructures.

2 Literature review

2.1. Vulnerability of communities and built environment structures

The term ‘vulnerability’ is defined as ‘*a set of conditions and processes resulting from physical, social, economic and environmental factors that increase the susceptibility of a community to the impacts of hazards*’ by the UN/ISDR (2004a, 2004b). Vulnerability does not only stand for vulnerability to hazard exposure but it represents a series of resultant state of social, economic, political, cultural, environmental, physical, technological underdevelopment processes, before, during and after disaster situations (McEntire, 2001; Jigyasu, 2004). Based on a similar argument, Wisner *et al.* (2003) claim that vulnerability involves a combination of factors that determine the degree to which someone’s life, livelihood, property and other assets are put at risk by a discrete and identifiable event. Eshghi and Larson (2008) note that vulnerability is influenced by factors such as location, state of housing, level of preparedness and ability to evacuate and carry out emergency operations. Different populations have different levels of vulnerability; this is one reason why hazards of a similar type and intensity can have quite varied effects on different populations (Eshghi and Larson, 2008). McEntire (2001) claims that there are innumerable variables interacting to produce future of increased vulnerabilities which in turn have been categorised under physical, social, political, economic and technological headings as depicted in table 1.

Table 1: Factors forming vulnerabilities

(Source: McEntire, 2001)

Type of vulnerability	Variables which interact to produce vulnerabilities
Physical vulnerability	Proximity of people and property to triggering agents Improper construction of buildings Inadequate foresight relating to the infrastructure Degradation of the environment
Social vulnerability	Limited education (including insufficient knowledge about disasters) Inadequate routine and emergency health care Massive and unplanned migration to urban areas Marginalisation of specific groups and individuals
Cultural vulnerability	Public apathy towards disaster Defiance of safety precautions and regulations Loss of traditional coping measures Dependency and absence of personal responsibility
Political vulnerability	Minimal support for disaster programmes amongst elected officials Inability to enforce or encourage steps for mitigation Over-centralisation of decision making Isolated or weak disaster related institutions
Economic vulnerability	Growing divergence in the distribution of wealth The pursuit of profit with little regard for consequences Failure to purchase insurance Sparse resources for disaster prevention, planning and management
Technological vulnerability	Lack of structural mitigation devices Over-reliance upon or ineffective warning systems Carelessness in industrial production Lack of foresight regarding computer equipment/programmes

2.2. Vulnerability of infrastructures

The risks on critical infrastructures due to their vulnerabilities and threats have been recognised and subject to discussion since along time, nevertheless, it attracted a great concern after the Unites States President's Commission on Critical Infrastructure Protection submitted a report which highlighted the topic of critical infrastructures in 1997 (Robles *et al.*, 2008). Infrastructure facilities may inherit all kinds of vulnerabilities as tabulated in table 1 (physical, technological, social, cultural, political, economic, and developmental) at different degrees. When infrastructure is built in disaster prone areas with much exposed to hazards, they easily become vulnerable to disasters. A fact regarding physically concentrated infrastructure has been raised by Parfomak (2008), which clearly articulate that infrastructures may be particularly vulnerable to geographic hazards such as natural hazards, epidemics, and certain kinds of terrorist attacks when they are physically concentrated in a limited geographic area. 'Geographic concentration' of critical infrastructure is defined there as '*the physical location of critical assets in sufficient proximity to each other that they are vulnerable to disruption by the same, or successive, regional events*' (Parfomak, 2008). This raises the issue of interdependency of infrastructures, which means that mutual dependency and interconnectivity of two or more infrastructure facilities with each other in different scale of complexity (Peerenboom *et al.*, 2002; Leavitt and Keifer, 2006). Authors such

as Robles *et al.* (2008), Oh *et al.* (2010) too discuss about interdependencies of infrastructures and various effects of this characteristic nature of infrastructures. There are certain infrastructures those heavily depend on services provided by some other infrastructure, for example a water supply and sanitation system depends on uninterrupted service provision of power. As US President's Commission on Critical Infrastructure Protection (1997) notes, high interdependencies and complexities of infrastructures would result in rather minor and routine disturbances turn into major failures in some other infrastructure. Oh *et al.* (2010) has presented a basic cell model indicating the inter-relationships between the infrastructure, associated industries and the communities as depicted in figure 1.

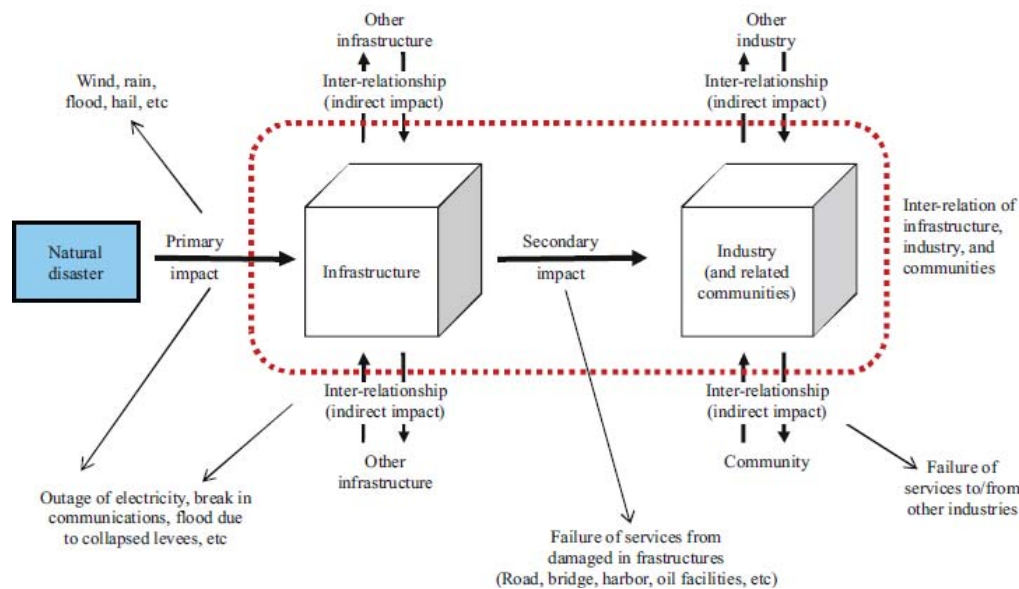


Figure 1: Interdependencies of infrastructure
(Source: Oh et al., 2010)

According to figure 1, the primary impact on infrastructure has indirect impact of inter-dependent infrastructure and secondary impact on associated industries and communities according to the level of inter-relationships between the infrastructure, associated industries and communities. Peerenboom *et al.* (2002) identify four types of infrastructure interdependencies as follows:

- Physical interdependency – material output of one infrastructure is used by another infrastructure
- Cyber interdependency – infrastructure depends on information transmitted through information and communication infrastructure
- Geographic interdependency – two or more infrastructures are located in the same areas, and can be affected by a local event

- Logical interdependency – condition of one infrastructure depends on the condition of another infrastructure in a way that is not physical, cyber or geographic (e.g. linkage through financial market)

The extensive use of technology has dramatically increased cyber interdependencies across all infrastructures and has contributed to their increased complexities (Peerenboom *et al.*, 2002). On the other hand, technical complexity may also permit interdependencies and vulnerabilities to go unrecognised until a major failure occurs (US President's Commission on Critical Infrastructure Protection, 1997). Despite the positive impacts of advance technologies they might result in cyber interdependency that makes infrastructures more vulnerable. In that way infrastructures would become more vulnerable to hazards due to their range of interdependencies. Depending on the nature of interdependency, infrastructures can be either or both physically or technically vulnerable.

In terms of physical and technological vulnerabilities of an infrastructural system, vulnerability can be generally distinguished between the system vulnerability and the vulnerability of each component (service lines, structures or control systems) (Jost, 2000). Conventional vulnerability assessments more often concentrates only on structural vulnerability (damage to the structural system), but the functional vulnerability is important because it is recognised that functional vulnerability is greater in frequency than structural vulnerability and functional failures precedes the structural failures (Jost, 2000). Not limiting to physical, technological, structural and functional vulnerabilities, infrastructure facilities can also be vulnerable in term of social, cultural, political, economical and developmental aspects. It is not only social environments encounter such vulnerabilities but also built environment facilities would also come across such vulnerabilities, may be due to inadequate capacities and cultural barriers of institutions and professional involved in planning, designing, construction and maintenance of those facilities; economical constraints affecting construction activities etc. The key role and the expertise that built environment discipline could bring forth in the development of society's resilience to disasters at each stage of the disaster management process is subject to discussion in much recent research such as Haigh and Amaratunga (2010), Boshier (2008), Boshier *et al.* (2009), Haigh *et al.* (2006). Haigh and Amaratunga (2010) call for inter-disciplinary strategy within the built environment discipline in order to contribute to increased resilience. Moreover, Boshier *et al.* (2009) researching on improved resilience to through multi-stakeholder approach, uncover the fact that key construction stakeholders' active role in mitigating flood risk is not sufficient and it is pre-construction phase of a building's life cycle the most critical phase when key stakeholders need to adopt flood hazard mitigation strategies. Wamsler (2006) presenting a very valid point claims that while construction sector play a key role in mitigating structural aspects the developers and planners should be able to positively influence the non-structural aspects of construction. Albeit the facts are placed in that way, this is an issue that needs to be investigated through empirical evidences due to lack of concern given over this issue in the current literature and the fact that there is no sufficient attention given by the built-environment professionals on integration of disaster risk management (Boshier *et al.*, 2007).

In this context, there are many reported incidences with high costs of damage on infrastructure due to various hazards in all over the world and in specific to Sri Lanka;

they may be due to natural hazards, man-made hazards. The nature of impact or the extent of damage on infrastructure could vary depending on the type of hazard it faces, its magnitude, and the prior preparedness (Freeman and Warner, 2001; Devi, 2010). The following table 2 presents literature findings of Freeman and Warner (2001) on various impacts that infrastructures have undergone due to a range of natural hazards.

Table 2: Some effects of disasters on infrastructure
(Source: Freeman and Warner, 2001)

Type of hazard	Possible impact on infrastructures
Hurricane, typhoon and cyclone	Damages to buildings, distribution and high-tension lines Damages to bridges, buildings and roads (through flooding)
Drought	Shrinkage damages building foundations and under-ground infrastructure Wind damage to roof tops Disruption to the water supply
Flood	Softening of building foundations Buried buildings and other structures such as roads Make hydro-power dams, water management systems ill function
Tsunamis	Destruction or damages to buildings, bridges, irrigation systems, roads, power distribution Water pollution

According to Devi (2010) and Freeman and Warner (2001), most disastrous hazards that severely damage infrastructures are floods, earthquakes, hurricanes and landslides. Robles *et al.* (2008) state that natural hazards such as those listed in table 2 could greatly affect infrastructures like transportation sector. For instance, Oh *et al.* (2010) recognise from their research on disaster impact analysis of critical infrastructure and associated industries that it is transportation infrastructures those are the most vulnerable to floods. Further to this, UN/ESCAP (2006) reports that half of the world's natural disasters and 70 percent of all floods have been recorded in Asian countries and much of the damage inflicted by floods is to the infrastructure. By some estimates, infrastructure losses account for 65 percent of all flood losses (UN/ESCAP, 2006). Claiming a similar fact, Freeman and Warner (2001) argue that flooding is one of the greatest threats to infrastructure. Further to note that approximately 50 percent of the World Bank's total lending over the last decade is equivalent to total cost of damage to infrastructure due to natural disasters in the Asian context (Freeman, 2000; UN/ESCAP, 2006). The annual investment needed for post-disaster reconstruction of infrastructure and economic recovery in developing countries of the Asian and Pacific region would require an estimated US Dollars 15 billion, for a total infrastructure-financing requirement estimated at US Dollars 55 billion per year (UN/ESCAP, 2006).

The destructive ocean waves of tsunami 2004 devastated the coastal infrastructure: roads, railways, power, telecommunications, water supplies and fishing ports in Sri Lanka, which were already in a seriously debilitated condition due to the ethnic conflict, maintenance negligence, lack of development investment and the effects of high rainfall and flooding in recent years (ADB *et al.*, 2005; ADB, 2005). Due to tsunami, erosion damage occurred on sections of the coastal highway network and a number of bridges were damaged or completely washed away. The road and rail

transport from Colombo to Hambantota in the South and some parts of the Puttalam district were badly damaged. Approximately eight hundred (800) kilometres of national roads together with approximately one thousand five hundred (1,500) kilometres of provincial and local government roads were damaged by the force of the tsunami, along with twenty five (25) bridges and causeways located in the North, East and South of the country (GoSL, 2005; RADA, 2006a; RADA, 2006b). In the rail sector, sections of track work, bridges, signalling and communications systems, buildings and some rolling stock were severely damaged on the one hundred and sixty (160) kilometres long coastline between Colombo and Matara (GoSL, 2005). Ten (10) of the twelve (12) fisheries harbours have been damaged, while eight (8) were completely destroyed (GoSL, 2005). While the electricity distribution system and service connections suffered damage throughout the tsunami affected areas, the water supply systems were reported with damages on portable water treatment, reticulation systems, and local supply systems, mainly ground water sourced suffered due to salt water intrusion (GoSL, 2005). The damage to Sri Lanka's infrastructure due to tsunami is estimated to be over US Dollars 1.7 billion (Gunasekara, 2006).

3 Research methodology

The main study, of which this research is based on, was conducted using case studies and the expert interviews. This paper is entirely based on the data collated from the expert interviews conducted in Sri Lanka and United Kingdom. Accordingly, three semi-structured interviews were conducted among experts involved in the field of infrastructure reconstruction and disaster management. The interview respondents were asked to express their views on how various factors forming infrastructure projects' vulnerabilities can be overcome using disaster risk reduction (DRR) strategies. The data gathered from the expert interviews were coded using NVivo (version 8) software and later the cognitive maps were prepared using the same software.

4 Findings

Findings of the expert interviews are presented in the following sections which intend to identify the effects of disaster risk reduction strategies on overcoming vulnerabilities of infrastructure projects.

4.1 Effects of disaster risk reduction strategies on overcoming vulnerabilities of infrastructure reconstruction projects

4.1.1 Overcome physical vulnerabilities of infrastructure reconstruction projects

Figure 2 shows the cognitive map developed on the effects of DRR strategies in overcoming the physical vulnerabilities of the infrastructure projects. Accordingly, the experts have identified how physical vulnerabilities of infrastructure reconstruction projects can be overcome by addressing following three factors: '*proximity of infrastructure reconstruction projects to natural hazards*' (181); '*degradation of the environment due to infrastructure reconstruction projects*' (182); and '*interdependencies of infrastructure projects with other infrastructures*' (183).

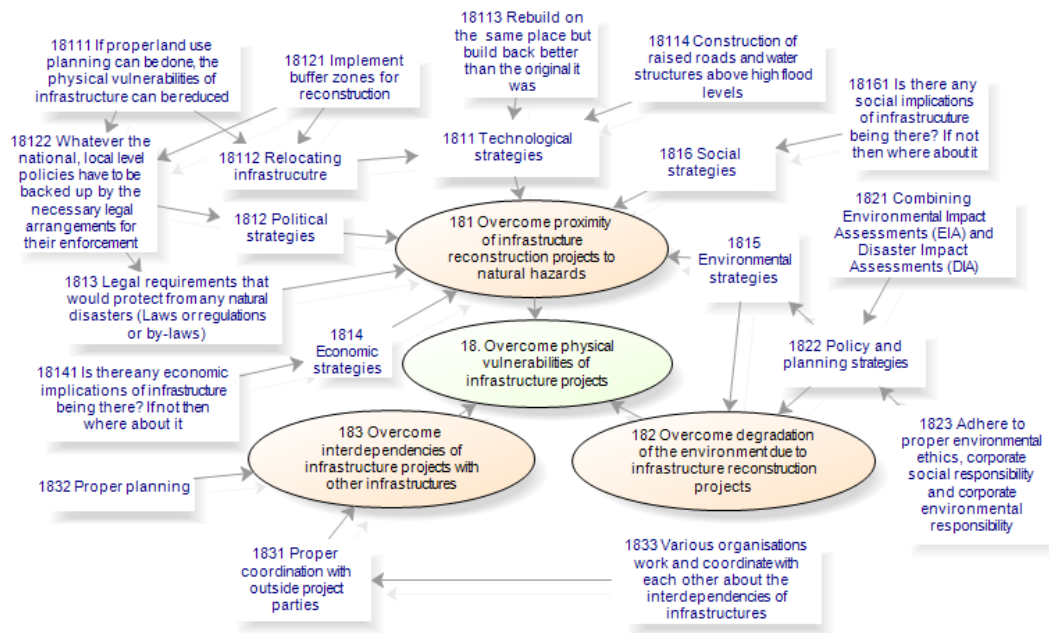


Figure 2: DRR strategies to overcome physical vulnerabilities of infrastructure reconstruction projects

'Proximity of infrastructure reconstruction projects to natural hazards' (181) was identified as one of very important factors to be addressed to overcome the physical vulnerabilities of the infrastructure projects. Expert interview respondents identified six key strategies to minimise the proximity of infrastructure reconstruction projects to natural hazards. The six strategies are social strategy, legal strategy, economical strategy, political strategy, technology strategy and environmental strategy. However, the most popular and obvious strategy among all was claimed as the technological strategies, which is referred here to physical/technical DRR strategies. Physical/technical strategies have become more popular due to pressure coming from societies to build back soon immediately after a disaster. However, this obviously raises some problems unless the infrastructures are not built back better than the original they were (18113). Therefore, physical/technical strategies have become prominent among other types of DRR strategies leaving them neglected. In this regard, physical/technical strategies such as construction of raised roads and construction of water structures above high flood levels were identified as the most effective strategies in reducing the exposure of infrastructures to natural hazards (18114). Further, physical/technical strategies such as proper land use planning (18111) and buffer zones for reconstruction (18121) are productive strategies which make infrastructure projects to be relocated into safer places. However, commenting on implications of physical/technical strategies, experts stated that in technological methods or reasons for overcoming it (proximity of infrastructures to hazards), the solution tend to be blanket. Accordingly, they raised the issue of ignorance of very complicated process involving more political, legal, environmental, social and cultural strategies that are able to provide more sustainable, long-term solution to proximity of infrastructure to natural hazards. The importance of having proper policy and planning strategies in achieving such long-term, sustainable solutions was therefore highlighted, which are considered to be some beneficial DRR strategies in overcoming proximity. However, whatever the national, local level policies

have to be backed up by the necessary legal arrangements for their enforcement. Proximity can be thus addressed through relevant legal provisions (18122). Therefore, it is important to consider whether there are any laws or regulations or by-laws that required to be met (1813). Furthermore, the environmental solutions in the form of natural protection strategies such as reforestation and vegetation of plants, looking at the problem of proximity from a social and economical eye are important in solving the problem of proximity of infrastructures to hazards. However, looking at the social and economic significance of the proximity of infrastructures to natural hazards again calls for the solutions such as relocation or adopting physical/technical strategies to strengthen the structures as appropriately.

'Degradation of the environment due to infrastructure reconstruction projects' (182) is an issue that can be overcome using environmental strategies (1815) and policy and planning strategies (1822). The policy and planning strategies exist in the form of environmental ethics, corporate social responsibility and corporate environmental responsibility. In that way, planning and policy strategies can address the problem of environment degradation through various means by guiding the parties to adopt necessary strategies to eliminate environmental degradation. Here, the environmental strategies refer to the natural protection strategies. Focusing on the Sri Lankan context, experts noted another important policy and planning issue to overcome the problem of degradation of environment. They emphasised the importance of linking regular EIA (Environment Impact Assessment) process and proposed DIA (Disaster Impact Assessment) process in the reconstruction projects. In that way, environmental degradation can be eliminated by adhering to relevant policy and planning strategies and natural protection strategies such as reforestation and vegetation of plants. However, what is exactly needed is a fine balance.

Infrastructures do normally interdependent with other infrastructures during their normal function times, during their construction or reconstruction and during disaster situations. Here, the *'interdependencies of infrastructure projects with other infrastructures'* (183) is particularly referred to interdependencies of infrastructures with others during disaster times because it is an issue which needs to be overcome when it negatively affects functioning of infrastructures. Some experts tend to look at interdependencies of infrastructure projects with other infrastructures by a trophic cascade". Trophic cascade is a concept from ecology which says that all of the components are interconnected in an eco system. Accordingly, when one of the components of the eco system is disturbed, the whole eco system is shown as to throw into chaos. In a similar manner, infrastructures too are linked together and may get those links disrupted due to various disasters. These disrupted links create much worse effects if they are not properly rectified or necessary contingency plans are not in place. If that is the case, the main reason of such weakness is attributed to lack of coordination between relevant parties. The organisations, the agencies, whether they are public sector or the private sector do not work and coordinate with each other about the interdependencies of infrastructures. Therefore, proper coordination with external entities responsible for interrelated infrastructures is identified as an important strategy not only at normal times but also during reconstruction phases. As interdependencies cannot be necessarily overcome by having a master plan because interdependencies between different infrastructures can be very different from one to another, planning

and consideration of interdependencies is important during reconstruction of a particular infrastructure considering the specific context of the project in focus. In this context, the experts argue that each infrastructure reconstruction project should necessarily install or plan for suitable contingency planning strategies depending on their own circumstances.

4.1.2 Overcome technological vulnerabilities of infrastructure reconstruction projects

This section intends to explore the DRR strategies that are potentially able to overcome the technological vulnerabilities of infrastructure projects. Figure 3 shows the cognitive map developed on the effects of DRR on technical vulnerability reduction of infrastructure reconstruction projects. Accordingly, the experts' views on the best ways to overcome the following three factors are discussed: '*project participants' over-reliance upon ineffective warning systems*' (191); '*project participants' inadequate foresights regarding new technology for reconstruction*' (192); and '*lack of detailed planning and structural mitigation of infrastructure reconstruction projects*' (193).

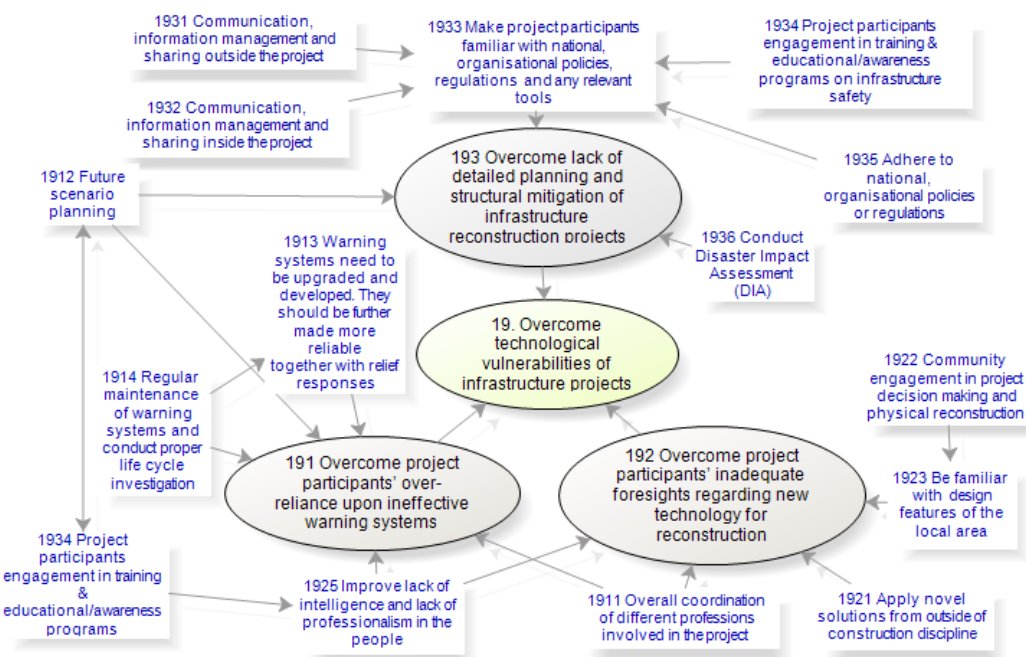


Figure 3: DRR strategies to overcome technological vulnerabilities of infrastructure reconstruction projects

The term 'warning systems' refers to both warning systems installed within or outside projects to receive advance warnings to infrastructure facilities regarding any potential disaster situations and warning systems to disseminate the warning to public (communities benefited from infrastructure projects) regarding any potential damage and potential service interruption of infrastructure facilities due to a forthcoming/already happened disaster. As noted by experts, 'unreliable warning systems' is a key issue exists particularly in developing countries. In this context, over reliance of ineffective or effective warning systems is an issue pertaining to developing countries which make infrastructure projects technologically vulnerable. Experts raised the issue of ability to protect infrastructures through warning systems and therefore encourage the infrastructure reconstruction entities to be more proactive. However, as

noted by all experts, it is quite important to regularly upgrade the warning systems. Regular maintenance is effective in this together with proper life cycle investigation (1914). In addition, the importance of proper line of communication when warning systems are activated was emphasised because sometimes problems occur in line of communication. For example, there were problems during the tsunami 2004 disaster In Sri Lanka regarding conflicting messages. If this happens, people get confused with advance warnings and the warning systems become less significant over time. Therefore, it is necessary to keep investing on them to upgrade them and also it is important to properly establish the line of communication. Infrastructure reconstruction projects need to establish such line of communication through proper coordination with relevant external entities during reconstruction and also during functioning of infrastructure facilities. In addition the importance of *'future scenario planning'* (1912) was emphasised by the experts as it is a powerful tool and an effective way to role-play the warning systems and emergency preparedness strategies, which makes project participants more proactive about imagining disasters and their effects while they are being aware about to what extent they should rely on such warning systems. This is much more similar to having necessary training and awareness programs on warning systems and how to react on them (1934).

Apart from that, *'project participants' over-reliance upon ineffective warning systems'*, and *'project participants' inadequate foresights regarding new technology for reconstruction'* both were attributed to lack of intelligence and lack of professionalism in the people and lack of coordination between different professionals within the reconstruction project. As a remedial measure, in addition to project participants' engagement in training & educational/awareness programs (1934), experts encourage more synergy within professionals with improved coordination of different professions involved in the projects (1911). Thus the experts identify the importance of overall coordination of different professionals involved in the projects to share their knowledge regarding warning systems and how to deal with such warning systems. In addition to these two strategies, project participants' inadequate foresights regarding new technology for reconstruction can be overcome by applying novel solutions from outside of construction to reconstruction projects (1921). In addition, it is imperative to be familiarised with the local construction technologies, design features and construction materials in order to overcome unnecessary reliance on new technologies which would not get along with the local contexts (1923). That can be achieved by improving community engagement in project decision making and physical reconstruction (1922). In that way, *'project participants' inadequate foresights regarding new technology for reconstruction'* can be overcome by integrating variety of DRR strategies into infrastructure reconstruction projects.

Infrastructure reconstruction projects can suffer from *'lack of detailed planning and structural mitigation of infrastructure reconstruction projects'* (193) due to lack of time available for further study the scenarios to come up with detail planning and necessary in detail structural mitigation measures and preparedness measures. This is where the importance of existing information on disaster risks becomes important. In these grounds, the proposed DIA to the Sri Lankan construction industry (1936) is identified as a very useful planning/policy tool in order to overcome this problem of lack of detailed planning and structural mitigation of infrastructure reconstruction projects. It is

because; it leads and guides the infrastructure reconstruction project designers to understand the issues to be considered during planning and in-detail structural designing of the projects. In addition, the experts highlighted the importance of having professionally qualified people, scenario planning and practising in eliminating lack of detailed planning and structural mitigation of infrastructure reconstruction projects. While the fact called ‘having professionally qualified people’ is obviously important, scenario planning and practising (1912) is important in imagining the future possible disasters and their possible effects on infrastructure facilities. These will improve designers’ thinking powers at the detail designing process. Apart from that, making the project participants familiar with national, organisational policies, regulations and any relevant tools (1933) is important in overcoming *‘lack of detailed planning and structural mitigation of infrastructure reconstruction projects’*. Communication, information management and sharing outside the project (1931); communication, information management and sharing inside the project (1932); adhere to national, organisational policies or regulations (1935); and project participants engagement in training & educational/awareness programs on infrastructure safety (1934) are identified as important in making project participants familiar with national, organisational policies, regulations and any relevant tools by the experts. These factors are discussed in detail under section 4.1.4 because it is not only *‘lack of detailed planning and structural mitigation of infrastructure reconstruction projects’* but also these strategies are important in overcoming *‘project participants’ carelessness, inadequate foresights regarding designing and reconstruction of infrastructure projects’*, which is a factor forming cultural vulnerabilities of the infrastructure projects.

4.1.3 Overcome social vulnerabilities of infrastructure reconstruction projects

Figure 4 depicts the cognitive map developed on the effects of DRR strategies on overcoming social vulnerabilities of infrastructure projects. The experts’ views on how DRR strategies could eliminate the factors called *‘project participants’ limited education (including insufficient knowledge) about disasters’* (201); and *‘marginalisation of specific project participants (e.g women)’* (202), which make infrastructure projects socially vulnerable are discussed here.

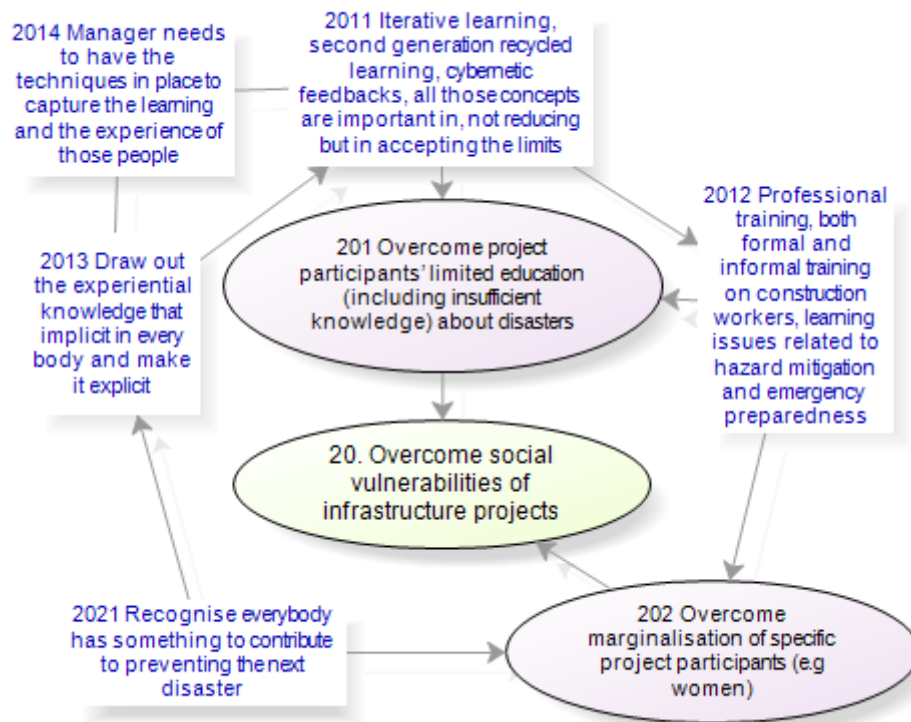


Figure 4: DRR strategies to overcome social vulnerabilities of infrastructure reconstruction projects

While developed countries undergo various procedures and documentation during post-disaster reconstruction, in some other countries the reconstruction is quite rigorous as that. In this regard, drawing out the experiential knowledge that implicit in everybody (with regard to disaster reconstruction) and make it explicit (2013) is an important strategy because otherwise, the implicit knowledge would not be properly transferred to necessary bodies by making them vulnerable with insufficient knowledge about disasters, their effects and strategies to reduce such effects. The managers need to have the techniques in place to capture the learning and the experience of those people (2014). Iterative learning, second generation recycled learning, and cybernetic feedbacks are important concepts, not reducing but in accepting the limits (2011). In that way, these learning processes are directly helpful in overcoming project participants' limited education (including insufficient knowledge) about disasters and on the other hand it can lead to proper professional training, both formal and informal training on construction workers and learning issues related to hazard mitigation and emergency preparedness (2012). As noted by all expert interview respondents, the issue of project participants' limited education (including insufficient knowledge) about disasters can be overcome to a certain extent by having proper professional training, both formal and informal training on hazard mitigation and emergency preparedness. As noted by the experts, limited education can only be solved by having proper capacity building programs and through making them familiar with existing guidelines, policies and the regulations at national, regional, local, organisational levels due to their lack of knowledge about those important guidelines and also due to lack of communication between major construction related sectors.

‘Marginalisation of specific project participants (e.g women) (202) is another factor forming infrastructure projects socially vulnerable to disasters. It is a factor closely related with the project participants’ limited education (including insufficient knowledge) about disasters and therefore it is quite important to recognise that everybody has something to contribute to preventing the next disaster (2021). Apart from that, adequate participation of all marginalised parties on professional training, both formal and informal training, learning issues related to hazard mitigation and emergency preparedness (2012) can be helpful in overcoming the problem of marginalisation to a great extent as in the same manner as explained in the previous paragraph.

4.1.4 Overcome cultural vulnerabilities of infrastructure reconstruction projects

This section explores how the factors forming cultural vulnerabilities of the infrastructure reconstruction projects can be overcome by integrating the concept of DRR into infrastructure reconstruction projects. Figure 5 shows the cognitive map developed in this regard. The experts’ views are based on the following three factors: *‘project participants’ objection to safety precautions and regulations’ (211); ‘dependency and absence of personal responsibility within infrastructure reconstruction projects (212); and ‘project participants’ carelessness, inadequate foresights regarding designing and reconstruction of infrastructure projects’ (213).*

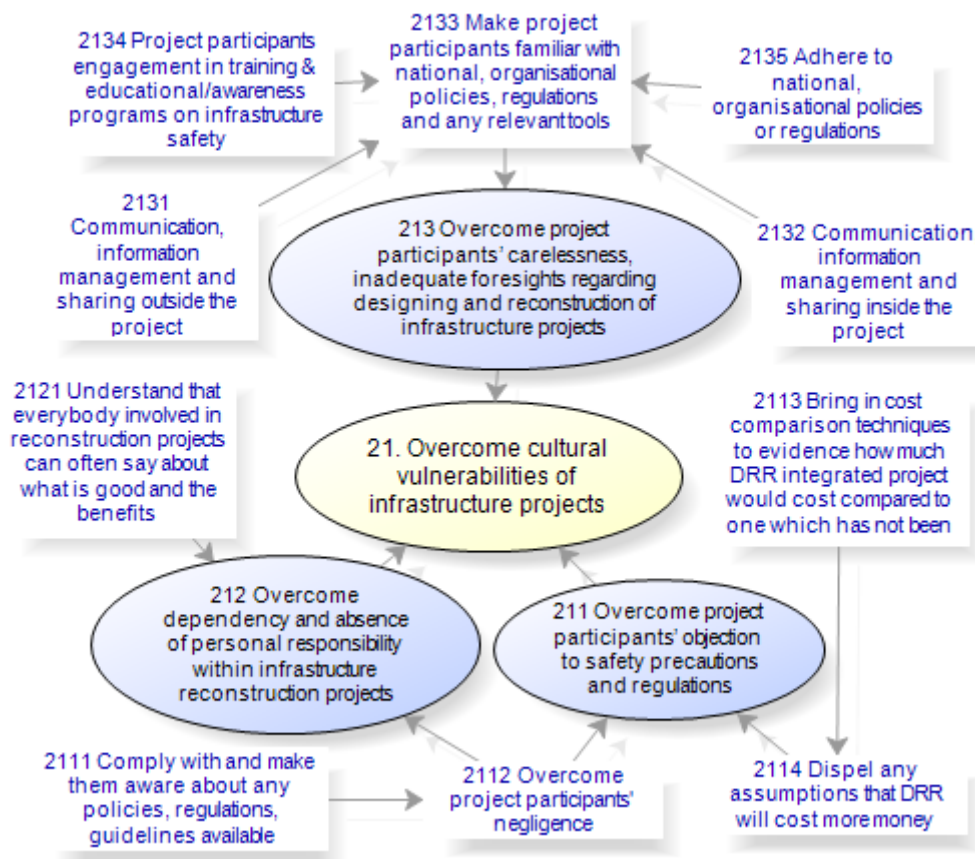


Figure 5: DRR strategies to overcome cultural vulnerabilities of infrastructure reconstruction projects

'Project participants' objection to safety precautions and regulations' (211) is a factor arise due to their negligence of DRR initiatives or due to the assumption that DRR would cost more money to the project. Hence the projects need to overcome project participants' negligence (2112) by adopting effective strategies. As reported by the experts, making project participants more aware about policies, regulations, guidelines available regarding integration of DRR practises to infrastructure reconstruction projects would be an useful strategy in this regard (2111). However, there are instances where logical, risk assessed decisions need to be taken based on the content and context of the particular situation, going beyond a set of generic rules. Accordingly, it is Project Managers' (or other relevant parties) responsibility to realise these situations and tackle them with good leadership. Apart from the negligence, as it was stated by the experts there may be some objections from project participants because of the assumption that building something which is going to be tsunami proof or earthquake proof or flood proof for example will cost more money. In this context, it is important to dispel such assumptions (2114) by some means. Therefore, bringing in cost comparison techniques to evidence how much DRR integrated projects would cost compared to one which has not been (2113) will be an effective strategy to overcome this *'project participants' objection to safety precautions and regulations'*.

As far as the issue of *'dependency and absence of personal responsibility within infrastructure reconstruction projects'* (212) is concerned, making project participants more aware about policies, regulations, guidelines available regarding integration of DRR practises to infrastructure reconstruction projects would be an useful strategy in this regard (2111); the same strategy explained above in overcoming project participants' negligence (2112) is applicable here too. On the other hand, as noted by the experts, it is important to understand that everybody involved in the reconstruction projects can often say about what is good and the benefits (2121). Thus *'dependency and absence of personal responsibility within infrastructure reconstruction projects'* can be overcome by eliminating project participants' negligence and by understanding that everybody involved in project can contribute to project through their ideas.

Although some experts did not agree with *'project participants' carelessness, inadequate foresights regarding designing and reconstruction of infrastructure projects'* (213) as 'carelessness', the problem was attributed to 'ignorance'. Some organisations are just oblivious to what they need to do. In contrast, some experts believe that the above factor is not something deliberate. It was therefore attributed to lack of recognition of different cultures and also the poor communication, miss communication. Thus the problem was attributed to lack of coordination. In this context, expert interview respondents suggested the importance of *'communication, information management and sharing outside the project'* (2131) and *'communication, information management and sharing outside the project'* (2132), basically to share hazard and vulnerability related data and to make project participants aware about existing national, organisational policies, regulations and any relevant tools (2133). As noted by the experts, there are helpful tools developed everywhere, some of which sign post the people where to get necessary information about risks to development in the area that they are undertaking the development. Further, it is good to have organisational level regulations in this regard (project participants' carelessness, inadequate foresights). But at the same time just having the national or organisational

policies or regulations is not enough because people should be familiar with what to do (2135). In that way, communication and information sharing is an useful strategy to overcome the problem of lack of information for reconstruction projects because it ultimately eliminates project participants' inadequate foresights regarding designing and reconstruction of infrastructure projects. In addition, the experts highlighted the importance of building the capacities of project participants on detail structural designing and planning with particular aim of disaster risk reduction by engaging project participants in training & educational/awareness programs on infrastructure safety (2134). Apart from that, all these strategies explained here on overcoming '*project participants' carelessness, inadequate foresights regarding designing and reconstruction of infrastructure projects*' (213) are useful in overcoming '*lack of detailed planning and structural mitigation of infrastructure reconstruction projects*', which is a factor forming technological vulnerabilities of infrastructure projects.

4.1.5 Overcome political vulnerabilities of infrastructure reconstruction projects

The most beneficial DRR strategies in overcoming the political vulnerabilities of infrastructure reconstruction projects are discussed against four factors: '*minimal support for disaster programmes amongst elected officials*' (221); '*inability to enforce or encourage steps for mitigation within infrastructure reconstruction projects*' (222); '*over-centralisation of decision making within infrastructure reconstruction projects*' (223); and '*isolated or weak disaster related institutions related to infrastructure reconstruction*' (224). Figure 6 shows the cognitive map developed in this regard.

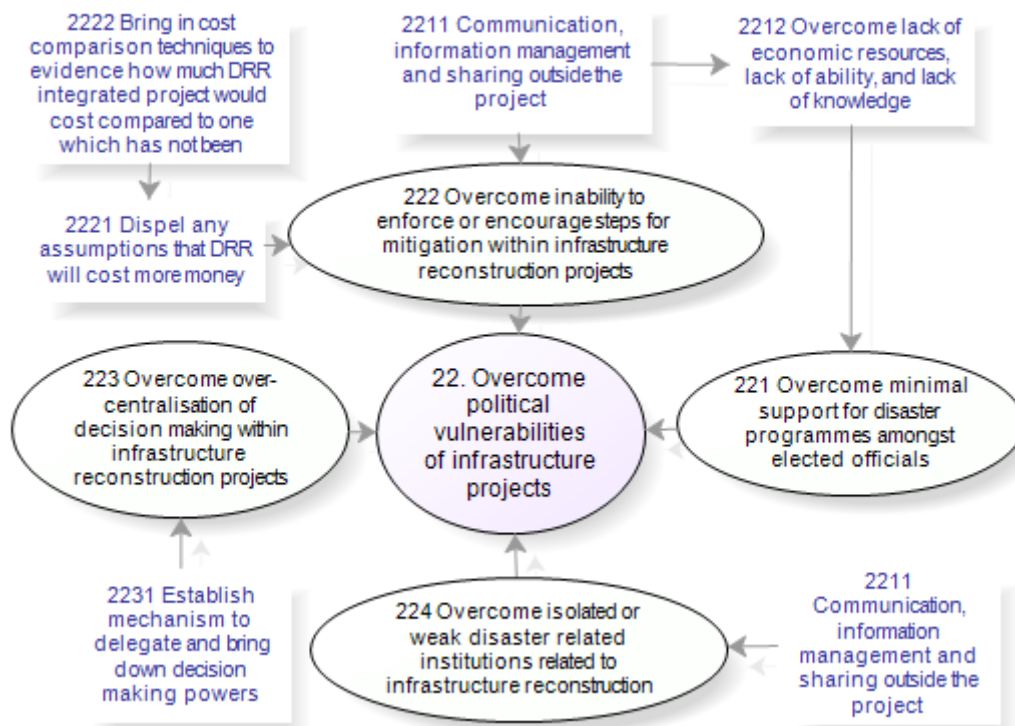


Figure 6: DRR strategies to overcome political vulnerabilities of infrastructure reconstruction projects

As majority of experts identified, most of the factors forming political vulnerabilities of the reconstruction projects are out of the project control. However, they claimed certain popular strategies, in managing such factors, which are sometimes fall outside the concept of DRR. Accordingly, '*minimal support for disaster programmes amongst elected officials*' (221) is claimed to be due to unbalance of all of the other factors, lack of economic resources, lack of ability, and lack of knowledge. Although some experts view it is not deliberate, some experts claim certain countries where communities get minimum support for disaster programmes due to religious or tribal grounds or due to cast grounds. On these grounds, the only strategy that infrastructure reconstruction projects can take up on overcoming minimal support from amongst elected officials is to improve communication, information management and sharing outside the project (2211). According to the experts, this might at least to some extent improve the links between the infrastructure reconstruction agencies and political agencies such as government ministries

In addition, poor communication was identified as an issue leading to '*inability to enforce or encourage steps for mitigation within infrastructure reconstruction projects*' (222) too. Therefore, appropriate communication with relevant entities outside and inside the projects is a strategy to overcome this factor. Apart from that, the inability is due to the perception that integration of DRR is going to cost a lot more. Bring in cost comparison techniques to evidence how much DRR integrated projects would cost compared to one which has not been (2222) is an effective way of overcoming this issue to a certain extent.

'*Over-centralisation of decision making within infrastructure reconstruction projects*' (223) is an internal political issue within the infrastructure reconstruction projects. It can be only solved through establishing a mechanism to delegate and bring down the decision making powers to as lower level as possible (2231). Although this strategy cannot be counted as a DRR strategy, the entire concept of DRR is a good opportunity to delegate the decision making powers to project participants based on their level of knowledge and experience on DRR and its effective integration to projects.

'*Isolated or weak disaster related institutions related to infrastructure reconstruction*' (224) is a factor forming infrastructure reconstruction projects politically vulnerable but which is again often considered out of project control. The reasons for such grounds based on the Sri Lanka context are attributed to the fact that the local governments are not appropriately looped into the system. The mechanism goes through the administrative hierarchy not the political hierarchy. Furthermore, there is a lack in the coordination there. In this context, communication, information management and sharing outside the project (2211) would be a better option to deal with whatever the relevant institutions in order to get maximum benefits from them.

4.1.6 Overcome economical vulnerabilities of infrastructure reconstruction projects

The effects of DRR strategies on overcoming the factors forming economical vulnerabilities of infrastructure reconstruction projects are depicted in the cognitive map shown in Figure . There were three factors identified from the literature review as factors forming infrastructure projects economically more vulnerable: *lack of funding and other resources for disaster prevention, planning and management within*

infrastructure projects' (231); *'failure to purchase insurance against potential economic losses of infrastructure projects'* (232); and *'project participants' pursuit of profit with little regard for consequences*' (233).

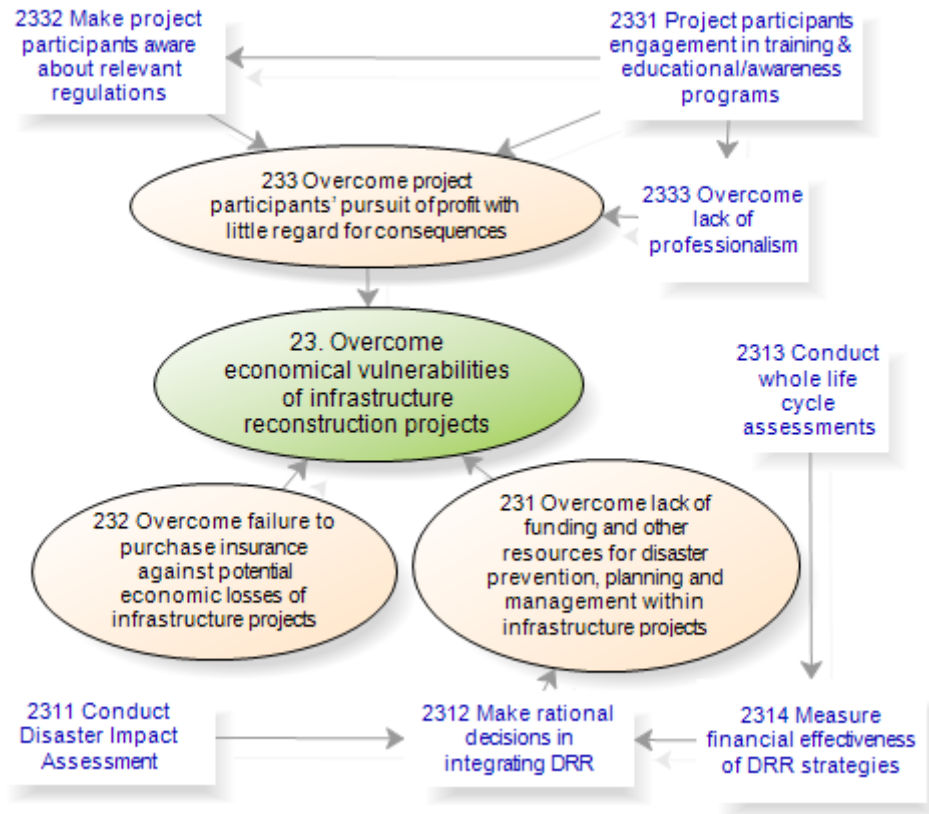


Figure 7: DRR strategies to overcome economical vulnerabilities of infrastructure reconstruction projects

'Lack of funding and other resources for disaster prevention, planning and management within infrastructure projects' (231) was attributed to the political issues by certain expert interview respondents. In this context, it is quite important to make rational and equitable decisions in better integrating DRR into infrastructure reconstruction. However, as far as the infrastructure reconstruction in Sri Lanka is concerned, there is a high chance of integrating the concept of DRR into foreign funded projects due to their financial status. Accordingly, the importance of conducting proper DIA within the infrastructure reconstruction projects was emphasised as a strategy which helps come up with rational decisions in integrating DRR into infrastructure reconstruction. Demonstrating more confidence view about the financial effectiveness of integration of DRR into infrastructure reconstruction, some experts emphasised that *"there is an assumption that disaster prevention and planning means you have to have more money. But it doesn't. It needs to be proven"*. Therefore it was suggested conducting whole life cycle assessments (2313), which facilitates measuring the financial effectiveness of DRR strategies (2314) and finally to make rational decisions about integrating DRR into infrastructure reconstruction projects.

Secondly, *'failure to purchase insurance against potential economic losses of infrastructure projects'* (232) was identified as a factor which needs to be decided depending on the necessity of such insurances. As noted by the experts, insurances are not necessarily viable every time. Apart from that, the insurance sector is not interested in insuring large scale construction projects in case they failed. In this regard, none of the experts came up with any means of overcoming *'failure to purchase insurance against potential economic losses of infrastructure projects'*.

Thirdly, *'project participants' pursuit of profit with little regard for consequences'* (233) is a factor identified to be overcome with proper training and awareness (2331) which could overcome lack of professionalism of project participants (2333) and make them aware about any relevant regulations (2332). Although the things are getting introduced such as legislation, overcoming *'project participants' pursuit of profit with little regard for consequences'* is an attempt to change the human and business nature. Accordingly, experts thoroughly believe that when an area is decided to be reconstructed, the contract should not be necessarily awarded to the cheapest but to companies which might have ethical stamps on doing things on right way and looking at things long-term and building things which are going to incorporate hazard mitigation features.

5 Conclusions

This paper investigated the vulnerabilities of infrastructure projects to natural disasters and the best possible DRR strategies to overcome such vulnerabilities. The critical literature review made known that the potential reason of damaging infrastructure facilities and their services is when natural or man-made hazards connect with vulnerable conditions of infrastructure facilities and communities. It further revealed that vulnerability represents a series of resultant state of social, economic, political, cultural, environmental, physical, technological underdevelopment processes, before, during and after disaster situations. Accordingly, there are innumerable variables interacting to produce future of increased vulnerabilities which in turn have been categorised under physical, social, political, economic and technological headings. As infrastructure project may inherit all kinds of vulnerabilities at different degrees, various DRR strategies can be integrated into the infrastructure reconstruction projects in order to overcome these vulnerabilities. Accordingly, the empirical evidences revealed that the most common type of DRR strategies are physical/technical strategies but paying attention to more complicated process involving political, legal, environmental, social and cultural strategies that are able to provide more sustainable, long-term solutions to vulnerabilities of infrastructures was emphasised as critical. Thus, it is not only important to have policies and guidelines that set up the environment but also making infrastructure reconstruction project participants adequately aware about such policies, guidelines and regulations are considered as important. In this context, the DRR strategies such as establishing proper line of communication through proper coordination with relevant external entities during reconstruction and also during functioning of infrastructure facilities; establishing future scenario planning; improve project participants' engagement in training & educational/awareness programs; improve more synergy within professionals with improved coordination of different professions involved in the projects; improving community engagement in project

decision making and physical reconstruction; conduct proper DIA; improve communication, information management and sharing outside the project; improve communication, information management and sharing inside the project; drawing out the experiential knowledge that implicit in everybody and make it explicit; adequate participation of all marginalised parties on professional training, both formal and informal training; bringing in cost comparison techniques to evidence how much DRR integrated projects would cost compared to one which has not been; eliminating project participants' negligence and understanding that everybody involved in projects can contribute to project through their ideas. Thus this paper reveals that physical/technical DRR strategies cannot stand alone to reduce to vulnerabilities of infrastructures. They need be well supported by the knowledge management strategies, natural protection strategies and emergency preparedness strategies.

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